# NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

## SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 1115

# SYMBOLIZING QUANTITATIVE DIFFERENCES ON COLOR CRTs

by

Matthew McGranaghan

Naval Medical Research and Development Command
Research Work Unit M0100.001-5003

Released by:

C. A. HARVEY, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

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NAVSUBMEDRSCHLAB

## SUMMARY PAGE


### THE PROBLEM

To determine if darker (less luminous) or lighter (more luminous) symbols on a CRT display are associated with "more", and if this is influenced by the type of display (simple rectangles or complex map) or the color of the background.

### THE FINDINGS

Darker symbols generally are interpreted as indicating "more." This tendency was stronger on map displays than on less complex displays. On the latter the background has relatively more effect. Choosing the more luminous symbol to represent "more" was associated with longer response times.

### APPLICATION

The findings are relevant to the design of information displays on CRTs in which the items are to be ranked.



### ADMINISTRATIVE INFORMATION

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ABSTRACT

This study examined the use of brightness to encode ordinal differences between symbols on CRT screens. The symbols were either U.S. states on a choropleth map or simple rectangles. The effects of background color and brightness were also measured. These results were related to the conventional practice with printed maps. Subjects compared pairs of symbols with different brightnesses, displayed on three background colors each of which had three brightnesses, and chose as quickly as possible which of the pair of symbols indicated "more." On both the maps and the rectangles subject responses indicated that the darker symbols meant "more". These CRT results are consistent with the convention used with printed maps.

# INTRODUCTION

Cartographers and human factors engineers share an interest in making it easier to extract information from visual displays. This is usually accomplished by designing the display to take advantage of characteristics of the human perceptual and cognitive systems. The visual system is sensitive to variations in size, shape, position, orientation, and color. Consequently, these may be used to symbolize information. For example, variation in the population of cities could be represented by size (larger circles representing larger cities) or by shape (squares for larger cities and triangles for smaller ones).

Color can be used similarly. Christ (1975), Silverstein (1982), and Neri and Zannelli (1984) have suggested guidelines for color coding information on CRT displays. Their attention focused on using color to code categorical differences. The present study is concerned with using color to symbolize quantitative differences.

Choropleth maps are often used to show quantitative differences over geographic space. In these displays, area symbols (such as color or pattern) are applied to enumeration districts, such as states or countries, to facilitate comparison of rates of occurrence. Percentage of the labor force which is unemployed, or number of cars per capita, are often symbolized in this fashion.

Cartographers typically use value or luminance contrast (rather than hue contrast) to symbolize quantitative differences, although the potential uses of luminance and saturation have also been recognized (Robinson, 1952; Jacobsen, et al., 1986). In printed maps, darker symbols conventionally represent "more." This convention, however, lacks both theoretical and experimental basis. Indeed, in the early 1800's, some choropleth maps used lighter symbols to represent "more" (Robinson, 1982). The convention has developed in practice since then.

Frequent appeal has been made to the printing process to explain the "dark is more" convention. More ink is applied to areas having more of the mapped phenomenon; hence, these areas of the map are darker. This assumes dark ink on a lighter page and also that map users are aware of, and consider, how different colors are printed.

With the increasing use of CRT screens for map displays, the question arises, does the printing convention apply to CRTs? Contrast on a CRT arises from emitting light rather than absorbing it as in printing. By reasoning analogous to that of the printer's, one might use more luminance (rather than more ink) to symbolize "more." The effect would be just the opposite of that with printed maps; an undesirable situation requiring display designers and users to vary their strategy according to the media used.

On the other hand, the contrast between the symbol and the background in the display may be the critical feature. The background may serve as an anchor in understanding the display. The background is typically the least important graphic component of the display; symbols which are like it would similarly be unimportant, and those that are most different would be most important. On a white page, a dark symbol is most different and is therefore seen as most important or "more." This is the conventional use of value in cartography. On a dark CRT screen, the most luminous symbol would have the greatest contrast and might seem most important.

This study examined how luminance contrast is understood in area symbols presented on a CRT. The goal was to establish whether greater luminance is taken to represent "more" or "less", and to determine the effects of the background color (chromaticity and luminance) and display complexity on this.

## METHOD

### Subjects

Seventeen men from the USN Submarine School volunteered to participate. They had normal color vision, according to the AO pseudoisochromatic plates. Those who usually wore corrective lenses wore them during the experiment.

### Apparatus

A VAX 730 computer was used to drive a Ramtek RM-9400 color CRT with a 34 X 27 cm screen. The chromaticities and maximum luminances of the screen phosphors are given in Table 1. A Photo Research PR-703A Spot Spectra Scan was used to measure the colors. A DEC LPA - 11 digital sampling device was used to collect the subjects' responses, which were entered using a telephone style numeric keypad.

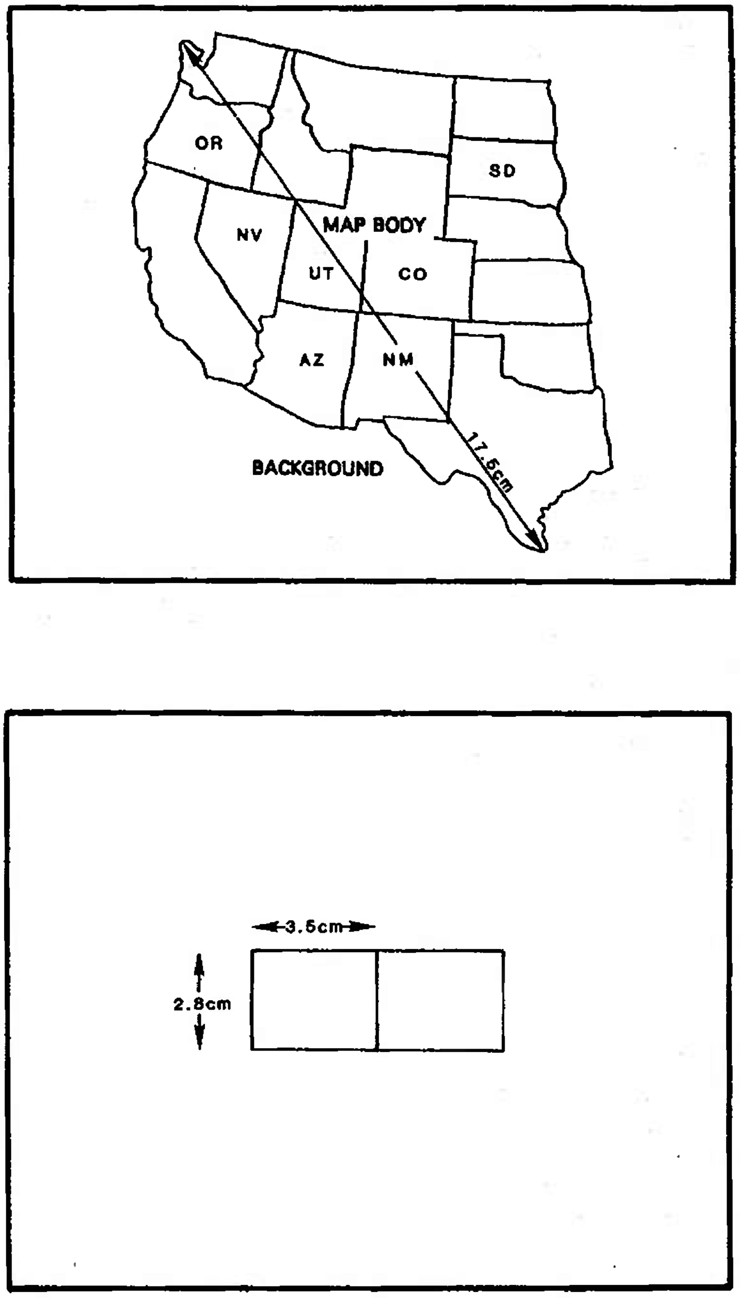


Figure 1. The displays. The size of the rectangles was made about equal to that of the states.

TABLE 1. Chromaticities (1931 CIE) and maximum luminance of screen phosphors (cd/m2).

| | x | y | luminance |
|---|---|---|---|
| Red | .6235 | .3490 | 39.19 |
| Blue | .1541 | .0696 | 23.84 |
| Green | .2826 | .6082 | 40.79 |

## Stimuli

The stimuli were either pairs of rectangles or states on a choropleth map of the western U.S. (Figure 1). The symbols were green and presented at five luminance levels (Table 2). Green was chosen because it provided a sufficient range of luminance to allow supra-threshold differences between seven luminances scaled by the square root of 2. There were three background colors (gray, green, and magenta--the complement of green). Each was presented at three luminance levels, chosen such that the background was either darker than any symbol, equal to the middle of the symbol range, or brighter than any symbol. The CIE chromaticities, luminances, and RAMTEK RGB coordinates of each are presented in Table 2. The viewing distance was about 80 cm, although this varied somewhat between subjects.

## Design

With each type of display, the subject compared each of the five symbol colors to every other color on each of the nine backgrounds. The darker symbol was on the left in half of the trials and on the right in half. There were a total of 360 comparisons with the rectangles.

TABLE 2. Colors as measured and their Ramtek RGB coordinates.

| Item | Luminance | x | y | R | G | B |
|---|---|---|---|---|---|---|
| Prompt | 9.007 | .3386 | .3431 | 88 | 133 | 64 |
| Background | | | | | | |
| dark gray | 4.505 | .3192 | .3486 | 62 | 111 | 51 |
| medium gray | 12.75 | .3166 | .3385 | 94 | 151 | 75 |
| light gray | 37.28 | .3159 | .3339 | 145 | 217 | 113 |
| dark green | 4.662 | .3017 | .5928 | 31 | 24 | 10 |
| medium green | 13.29 | .2891 | .6033 | 30 | 174 | 9 |
| light green | 38.32 | .2849 | .6057 | 31 | 253 | 8 |
| dark magenta | 4.626 | .3401 | .1999 | 92 | 71 | 72 |
| medium magenta | 13.46 | .3353 | .1958 | 141 | 91 | 109 |
| light magenta | 38.09 | .3311 | .1910 | 217 | 120 | 166 |
| Symbol Colors | | | | | | |
| dark green | 6.667 | .2965 | .5971 | 30 | 138 | 10 |
| | 9.590 | .2926 | .6008 | 30 | 155 | 9 |
| | 13.53 | .2897 | .6027 | 30 | 174 | 9 |
| | 19.49 | .2877 | .6041 | 30 | 197 | 9 |
| light green | 27.17 | .2861 | .6051 | 30 | 222 | 8 |

Note: Luminance is in cd/m2. Chromaticity is in CIE 1931 x,y.

With the maps, there were, in addition, four spatial arrangements. These reflected the ways in which the target states could be related to each other and to the background:

(1) adjacent to each other and to the background
(AZ and NM)
(2) adjacent to each other but not to the background
(UT and CO)
(3) not adjacent to each other or the background
(NV and CO)
(4) not adjacent to each other but adjacent to the background
(OR and SD)

The subjects thus made 720 comparisons with the maps, each with a different randomly generated pattern. The map comparisons were divided into two groups of 360, giving three sets of 360 images. The order in which these sets were presented was balanced across subjects. A random order of presentation was used in each set. The starting point in each set was balanced across subjects.

Procedure

The subject was seated in front of the CRT and handed the keypad. He then received instructions for, and completed ten practice trials with, the rectangles. The instructions were as follows:

> You will be shown a series of displays that simulate a control panel for monitoring two processes such as the rate of revolution of two shafts or the flow through two fittings. One is indicated by the box on the left, the other by the box on the right. For each display decide which process (left or right) seems to be doing "more". Indicate this by pressing the top left button (#1) to indicate the left box and the top right button (#3) to indicate the right box. Do not worry about consistency from trial to trial; use the visual impression from each display. Please work as quickly as possible without sacrificing accuracy. The boxes to compare will appear where the gray rectangles are immediately after the beep.

After this, the subject was read the following instructions for the map displays:

> Now you will see a series of maps showing the distribution of some phenomenon over the U.S. The distribution is made-up and does not reflect anything in particular. On each map, you are to compare a pair of states and determine which seems to have "more" of the mapped phenomenon. Indicate the state on the left by pressing the top left button on the keypad or the state on the right by pressing the top right button. Base your answers on the visual impression created by each map. Please work as quickly as possible without sacrificing accuracy. The states to be compared will appear on the screen in gray, and a beep will sound just before the map on which to compare them appears.

Ten practice trials using map displays followed these instructions. All subjects demonstrated that they understood the task and the operation of the apparatus.

The presentation of the stimuli was under computer control. With the rectangles, each trial began by presenting the rectangles illuminated with a light gray against a black background for two seconds. With the map, each trial began by presenting the map outline with the two states to be compared illuminated with a light gray on a black background for two seconds. This prepared the subjects to compare the proper states without having to be able to identify them by name. A beep sounded 1/4 second before the prompt was removed and the test display presented. The subject decided which of the two test symbols represented "more" and entered his choice on the keypad. The computer recorded the choice and reaction-time, and then presented the prompt for the next trial. There was a rest pause between groups. All the subjects completed the experiment within 1.5 hours.

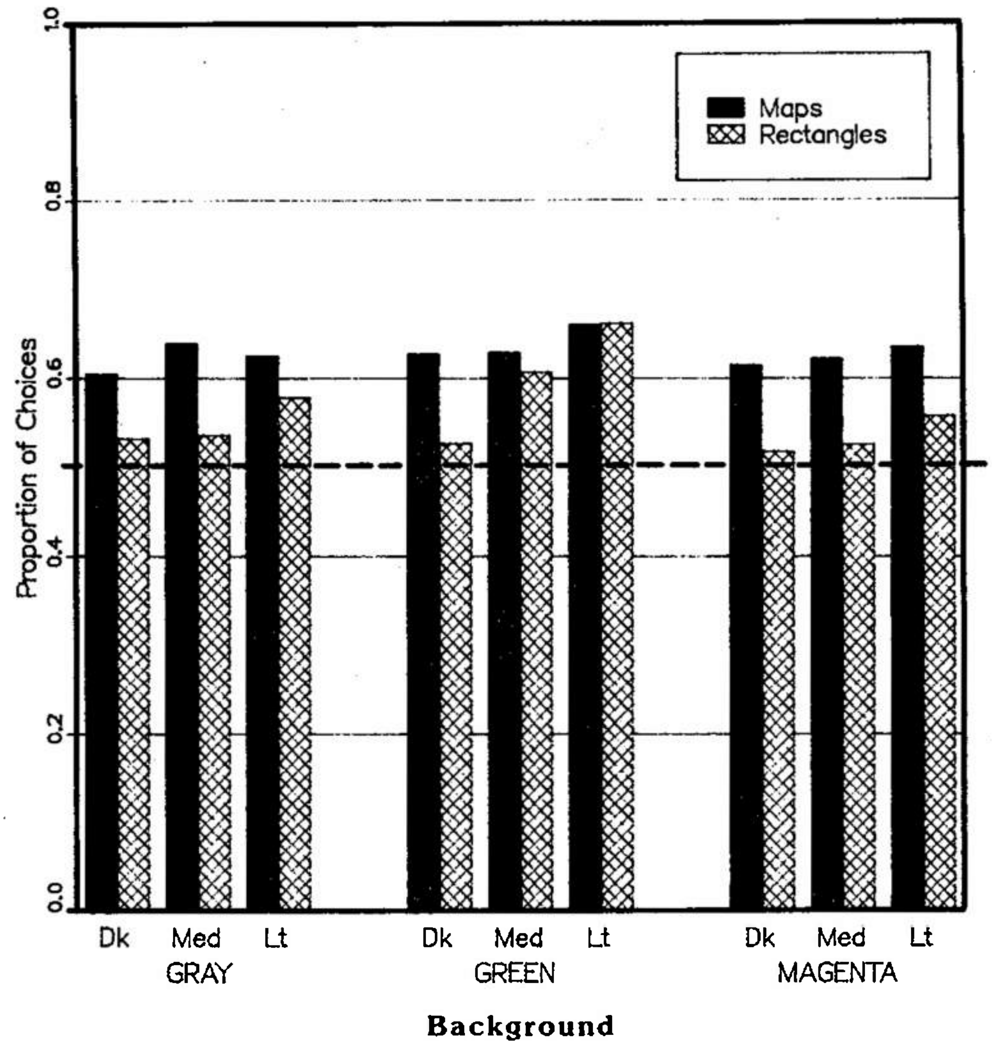


Figure 2. The proportion of "dark is more" choices made against the various backgrounds for both the rectangles and the map.

## RESULTS

Dark symbols were taken to represent "more." On the maps, the darker symbol was chosen as "more" in 61% of the trials. The binomial distribution suggests this percentage is highly unlikely ($p < .001$) if the "dark" and "light" choices are equally probable. With the rectangles, dark was "more" 56% of the time, again, unlikely ($p < .005$) under the equal probability assumption.

A paired t-test (paired by background) indicated that the mean proportion of dark choices differed significantly between the map and the rectangle displays ($t = -5.37$, $df = 8$, $p < .001$). For both display types dark is "more" but there are differences in the way these displays are treated by subjects.

Figure 2 shows the proportion of choices in which the darker symbol was chosen as "more" on each background for both the map and the rectangle displays. The darker symbol was chosen as "more" in the majority of trials with each background on both displays. The light green background produced the highest proportion of "dark is more" responses for both the rectangles and the map (both 66%). The dark magenta background produced the lowest proportion of dark choices with the rectangles (52%) while the dark gray background did so for the maps (60%).

The responses for the rectangles and the maps were examined separately. Repeated measures analysis of variance showed that background hue, luminance or their interaction did not account for the differences in proportion of dark choices among the maps. Exhaustive paired t-tests indicated a significant difference only between the proportions on the dark gray and medium gray backgrounds ($t = 2.97$, $df = 16$, $p < .01$).

For the rectangles, repeated measures analysis of variance found background hue affected the proportion of dark choices ($F(2,32) = 4.57$, $p = .018$). Paired t-tests indicated significant differences between the medium green and medium magenta grounds ($t = 2.97$, $df = 16$ , $p = .009$) and between the light green and the medium magenta grounds ($t = 2.31$, $df = 16$, $p = .034$). In both cases, the medium magenta background had a lower proportion of "dark is more" choices.

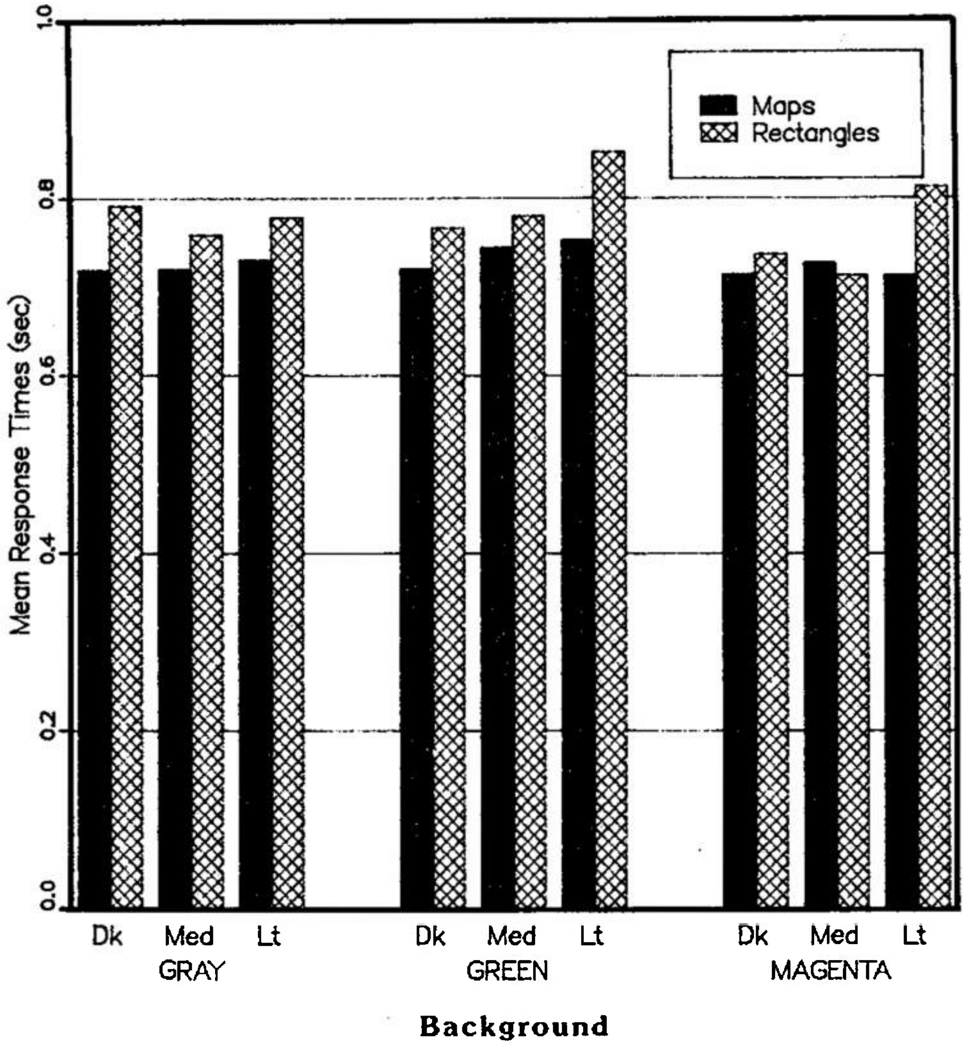


Figure 3. The mean response times made to the rectangles and the map against the various backgrounds regardless of the decision.

The mean response times for each ground and both types of display are shown in Figure 3. These response times disregard whether the subject chose darker or lighter to represent "more." The subjects responded about .05 seconds faster to the map (.73 + .53 sec) than to the rectangles (.78 + .60 sec). This difference in response time is significant ($t = 5.56$, $df = 17406$, $p < .001$), indicating some difference in the effort required to process these displays.

Each subject's mean response time for each background was calculated for the maps and the rectangles. Repeated measures ANOVA indicated no significant differences in response time attributable to background hue or luminance or their interaction among either the maps or the rectangle displays. However, paired t-tests revealed significant differences in mean RT among five pairs of backgrounds with the rectangle displays. These are enumerated in Table 3. In each case a medium or dark background is associated with the faster response and a light background with the slower response. The medium magenta background, which had the fastest mean RT, is significantly faster than each of the three light backgrounds.

TABLE 3. Background pairs between which t-tests found significant differences in mean RTs with the rectangle displays.

| Backgrounds | | | | |
|---|---|---|---|---|
| faster | slower | df | t | 2-tail p |
| medium magenta | - light gray | 16 | 2.65 | 0.017 |
| medium green | - light green | 16 | -2.99 | 0.009 |
| medium magenta | - light green | 16 | 2.59 | 0.020 |
| dark magenta | - light magenta | 16 | -2.28 | 0.036 |
| medium magenta | - light magenta | 16 | -3.24 | 0.005 |

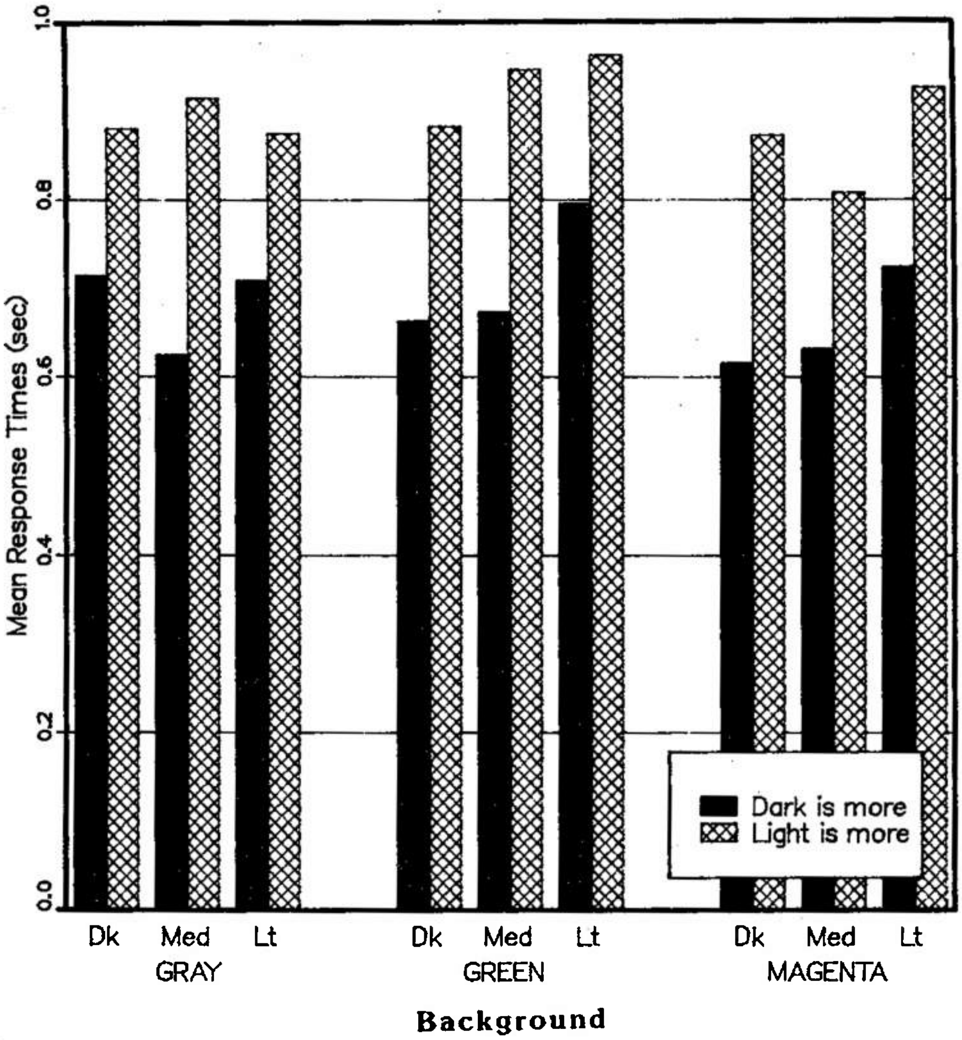


Figure 4. The mean response times for the "dark is more" and the "light is more" decisions with the rectangles.

The response times were also analyzed considering the subjects' choices. Subjects made "dark is more" choices more quickly than "light is more" choices. This was true for both the rectangles (.68 $\pm$ .57 vs .89 $\pm$ .62 sec, t= 13.4, 5449.52 d.f., 2-tailed probability < .001) and the maps (.68 $\pm$ 1.69 vs .84 $\pm$ 1.19 sec, t = 5.92, df = 11653.26 , 2-tailed probability < .001).

Figure 4 presents the mean reaction times for both "light" and "dark" choices using the rectangles. Repeated measures analysis of variance indicated no significant effect of background hue, value or their interaction on the RTs for the dark is more choices, but paired t-tests indicate that the RTs for the medium green background are significantly different (faster) from those with the light magenta background (t= -3.25, df = 15, p = .005) and the light green background (t = -2.31, df = 15, p = .036). Among the light choices, repeated measures ANOVA found no significant effect of background hue, value or their interaction; paired t-tests also found no significant differences.

The mean reaction times for both "light" and "dark" choices using the maps are shown in Figure 5. For both the "dark is more" and the "light is more" choices, repeated measures ANOVA found the effects of background hue, value and their interaction were not significant. Paired t-tests found no significant differences among either type of choice.

## DISCUSSION and CONCLUSIONS

The majority of trials on all backgrounds and with both types of display resulted in "darker is more" choices. These results show that the conventional use of darker area symbols to represent "more" is appropriate for both maps and simple control panel displays on CRT screens.

Not only was the "dark is more" response most common, it was also approximately .2 sec faster than the "lighter is more" response. This result was unexpected. Subjects were allowed to choose either dark or light symbols on each trial. It seems plausible that response times would be equal for either choice. It is not clear why they were not. Further experimentation is required to determine why this latency exists.

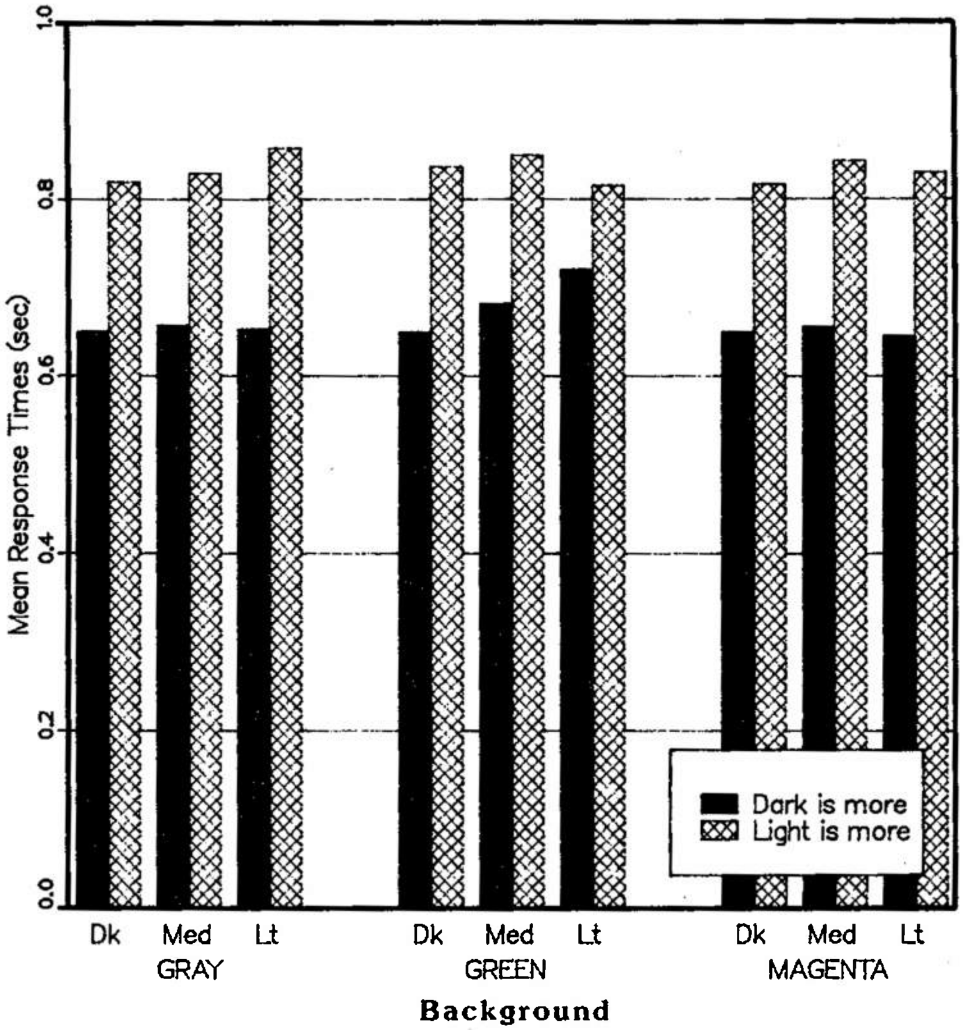


Figure 5. The mean response times for the "dark is more" and the "light is more" decisions with the map.

The effects of background hue and luminosity on subject choices are not clear. They had essentially no effect on task performance with the maps but had somewhat more pronounced effects with the rectangles. The trend among the rectangles in Figure 2, an increasing proportion of "dark is more" choices with increasing background luminance, suggests that luminance contrast is important in structuring the meaning of the display. However, this was not borne out by analysis of variance.

Different backgrounds enhanced different aspects of task performance with the rectangles. Some backgrounds were associated with a greater tendency for darker to be "more." The light green background had the greatest proportion of "dark is more" choices, and significantly more "dark is more" choices than the medium magenta background.

Other backgrounds enabled faster responses. Disregarding the subject's choice, medium magenta was the fastest background, and was significantly faster than any of the light backgrounds. Considering only "dark is more" choices, the dark magenta background was fastest (Figure 4), but only the medium green background was significantly faster than any other backgrounds (specifically, the light green and the light magenta backgrounds).

Thus, at least two backgrounds were opposed in their effect on task performance. The light green background is advantageous for helping individuals interpret a display as intended but this interpretation will be slower than on a medium magenta background. On the other hand, the medium magenta background would offer faster processing, but less confidence that the reader will interpret the display as intended.

Several differences in response were associated with the display type. The proportion of "dark is more" choices was higher with the maps. Also, responses for the maps were faster than those for the rectangles.

The prima facie difference between the display types is the relatively greater complexity of the maps. The rectangles also have a larger portion of the display given to the background and both symbols contiguous to the background. Each of these might be expected to increase the influence of the background in responses to the rectangles.

The map itself may effect the comparison of two symbols within it. Map comparisons were not made on a single background color but rather against the set of symbols used to color the rest of the map. These provide a comparable field on which all the map comparisons were made (see Brou, et al., 1986, for a discussion of how this would impact color recognition tasks). This relatively stable field may be easier to make judgments against than one (like with the rectangles) in which the background is changing from trial to trial. This may explain the map RTs being significantly faster than the rectangle RTs, it also would indicate how display complexity might facilitate performance of some tasks.

The results of this study indicate that darker symbols should be used to represent "more" on CRT displays; the majority of individuals interpreted these displays in this way and did so faster than those adopting alternate interpretations. Further, some background colors tend to produce better agreement on symbol order, while other backgrounds produce faster comparisons. Finally, the complexity or configuration of a display also influenced judgments of relative magnitude. These factors and the intended use of a display should be considered in designing visual information displays.

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